Engineering Psychology

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Week-06

Lecture-16

Motor skill and control - 2

Namaskar. In the last class, I explained how movement influences human engineering and how tracking movements can aid in designing better controls. I provided the example of a crane driver who uses his crane to perform essential actions for loading and unloading at a ship dockyard. I demonstrated how, through the use of a few levers, the operator can successfully complete the assigned tasks. In previous classes, we explored the physiological and cognitive constraints of humans, how these constraints assist human psychologists, and their significance in the field of human engineering psychology.

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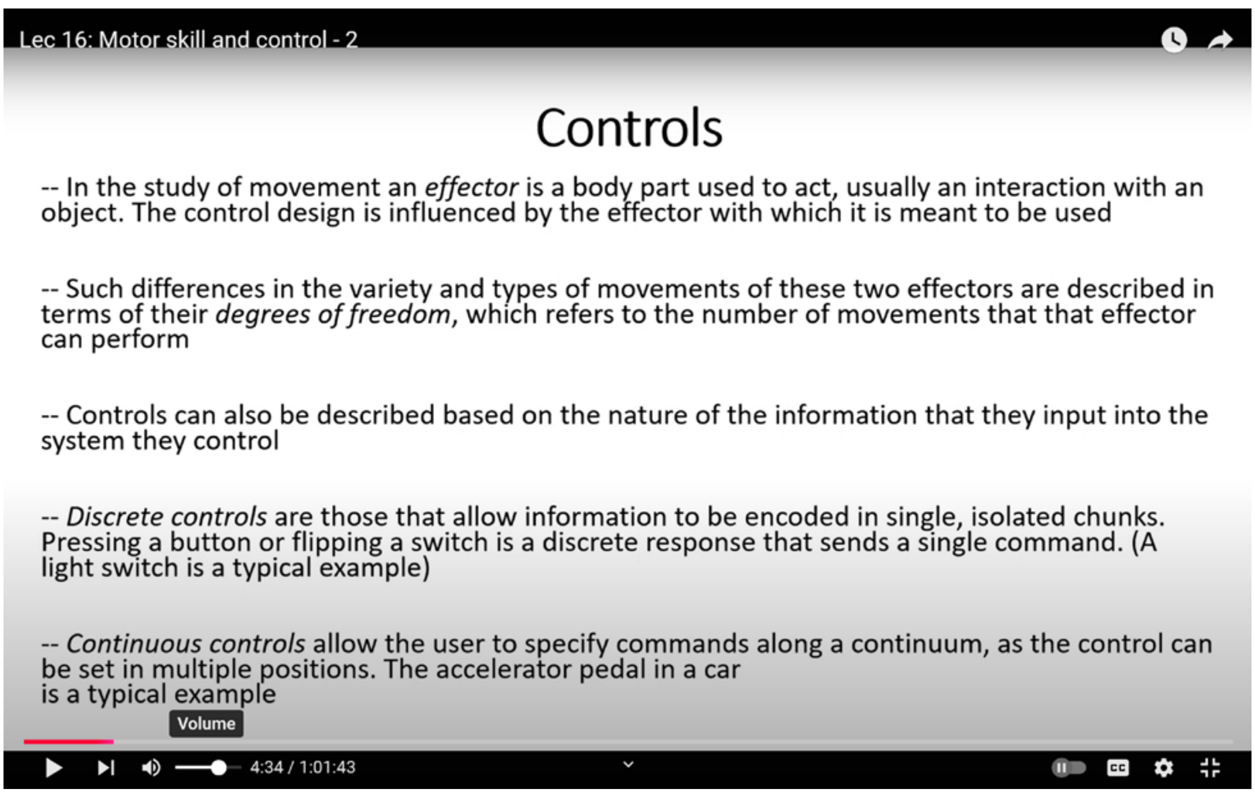

In this particular section, we will examine how the execution aspect of information processing contributes to the design of improved systems. I created a scenario in which I illustrated how the crane driver realizes that a certain accident is imminent and how he manipulates the lever to stop the crane in mid-air. We dissected this entire scenario in terms of his movements. I discussed reaction times and movement times, as well as how open-loop and closed-loop systems facilitate movement accuracy. The focus was on those factors that enable movements to be executed more accurately and with fewer errors.

I explained how the Hick-Hyman Law and Fitts' Law address the size of controls and the distances involved in making precise movements, emphasizing the trade-off between speed and accuracy. In today's section, we will focus on controls. Whenever a human moves, this motion is directed towards the control. Controls are a vital aspect of our daily lives, serving as interfaces that connect human output to machine input, whether in the workplace or at home.

In simple terms, controls are the components that interact with humans to execute specific actions on their machine counterparts. Therefore, let us discuss what controls are and the various ways to design them to enable better and more accurate, error-free decisions. We will also examine certain principles that guide the development of controls.

In the study of movement, a part of kinesiology, an effector refers to a body part utilized to perform actions, typically in interaction with an object. Control design is influenced by the effector with which it is intended to be used. The effector is the body part that interacts with the control and initiates the necessary changes. Two common effectors are the hand and the leg. The hand can perform various movements, such as adjusting dials and rotating knobs. The foot, on the other hand, is used for actions against pedals or simple movements like swinging machines. Additionally, there are eye-controlled motions and brain-controlled motions, but since most levers around us are operated through hand and leg movements, we will concentrate on those.

The differences in the variety and type of movements made by the leg and hand can be described in terms of degrees of freedom, which refers to the number of distinct movements an effector can perform. The hand, equipped with an opposable thumb and four nimble fingers, can execute many actions. In contrast, the foot is limited in its range of actions; while the toes can perform some individual movements, the overall action of the foot involves the collective movement of all toes.

For example, pressing a gas pedal exemplifies this limitation. Similarly, the wrist can execute clockwise and counterclockwise motions to a significant degree, whereas the ankle cannot achieve such motions. Therefore, the range and type of motions the hand can perform are far greater than those of the foot. This principle must be considered when designing levers and controls.

Controls can also be classified based on the nature of the information they input into the system they govern. Some controls input specific numbers, others input particular motions, and some are designed to input certain types of information. Thus, a control can be categorized according to the information it manages, taking input from the human and encoding it for the system to function effectively.

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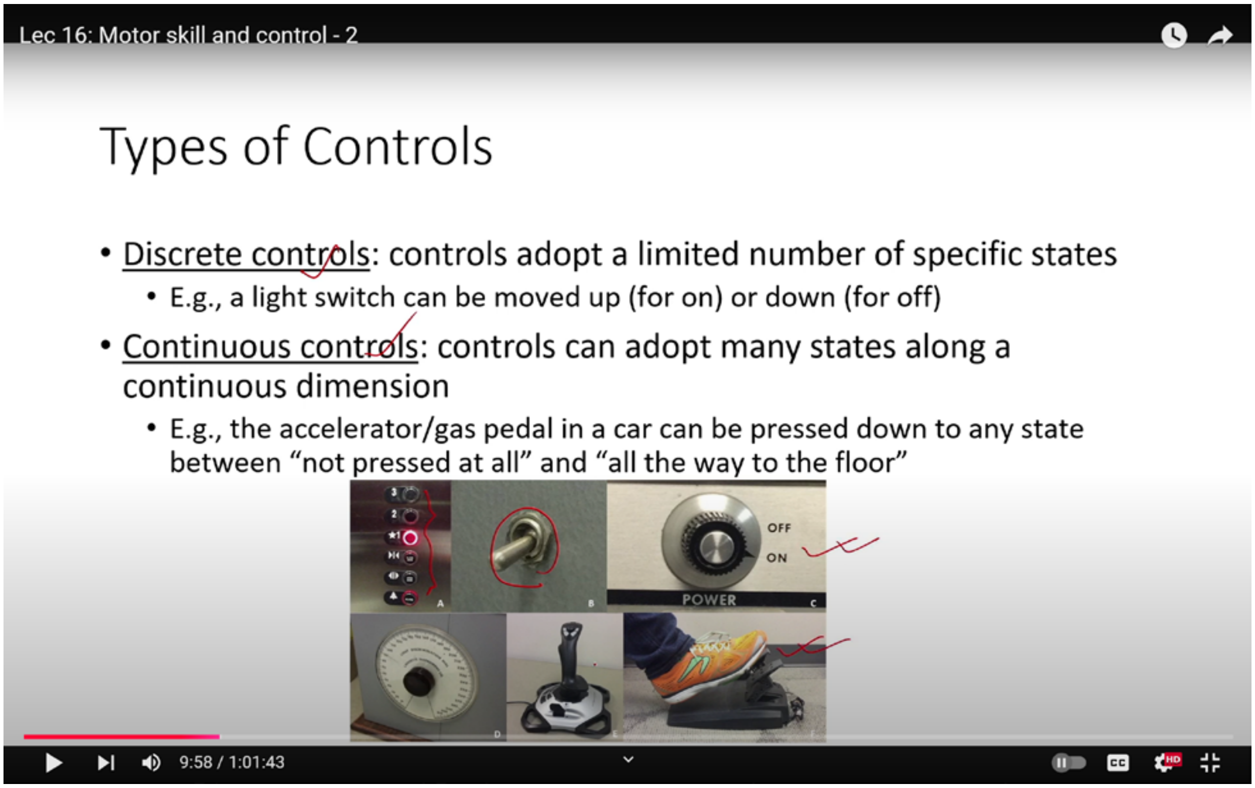

In terms of motion, controls can be divided into two categories: discrete control and continuous control. Let us explore what discrete and continuous controls entail. As the name suggests, discrete controls have fixed positions, such as an on/off light switch. In contrast, continuous controls manipulate a variable of interest or track changes in a fluid manner. Discrete controls allow information to be encoded in single, isolated chunks.

Pressing a button or flipping a switch is a discrete response that sends a signal or command. A good example of this is a light switch, which has two positions: it can either be on or off. In the United States and many Western countries, the switch is in the "on" position when it is flipped toward the ceiling, while it is "off" when pressed down toward the floor. Conversely, in many Asian countries, the orientation is reversed. Thus, discrete controls are characterized by fixed positions.

On the other hand, we have continuous controls, which allow the user to specify commands along a continuum. Because these controls can be set to multiple positions, a typical example is the accelerator pedal in a car. The accelerator cannot simply be placed in a high or low position; rather, the amount of pressure applied to the accelerator determines how fast the vehicle moves. Similarly, certain knobs, such as the regulator knob on a fan, serve as examples of continuous controls. These knobs have numbers marked on them that dictate the fan's speed, demonstrating the principle of continuous control.

As previously explained, these examples illustrate the differences between discrete and continuous controls. This provides clear instances of both types. Most of these controls are user-friendly, but it is essential to understand what each control does. The more explicit a control is, the easier it will be for the operator to understand and operate it effectively. To address this need, control coding was developed.

Control coding is a method of assigning meaning to a control itself, enabling the operator to comprehend its function with minimal effort and to issue commands for performance. A crucial aspect of designing any control is ensuring that the user understands what it does and can easily select the desired control. This design should incorporate a property known as affordance. Affordance implies that certain objects possess inherent meanings or provide indications of the actions that should be performed upon them. A good example of this is the "on" button on a printer. When the button is off, it is slightly elevated above the surface, suggesting to the user that it can be pressed. Once depressed, the button activates the printer. This exemplifies affordance.

When a user must select among multiple controls, they encounter the challenge of control discrimination. Control coding is significant because it quickly conveys meaning to the operator about what a control expects and the output it will produce. In scenarios where several control levers are present, control coding serves to highlight individual controls amidst a multitude. For instance, consider the cockpit of an aircraft, which contains numerous buttons, dials, and controls. A lapse in attention can result in serious errors.

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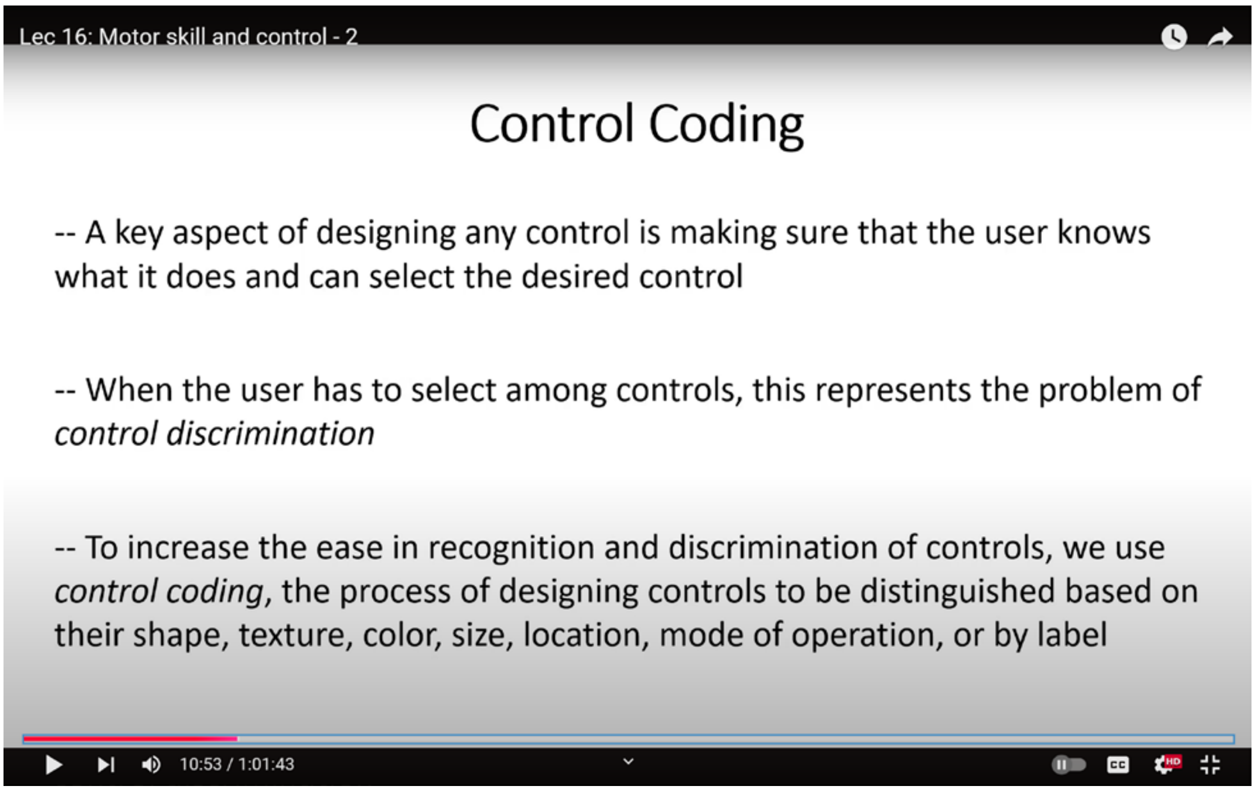

For this reason, controls in an aircraft cockpit are coded based on various properties, such as shape, movement, or other distinguishing characteristics. By coding controls according to the actions they perform, the cognitive load required from the user to operate that control is reduced. Different coding methods allow the operator to easily discern which control performs what function. Thus, control discrimination is a critical element of control coding.

To enhance the ease of recognition and discrimination of controls, we employ control coding. This process involves designing controls to be distinguishable based on their shape, texture, color, size, location, mode of operation, or labeling. These factors play a crucial role in making controls easily distinguishable from one another.

Next, we will examine each of these factors individually to explain their significance and how they can contribute to the development of better controls that are easily discriminable from one another. Let us begin with the first factor, which is shape coding.

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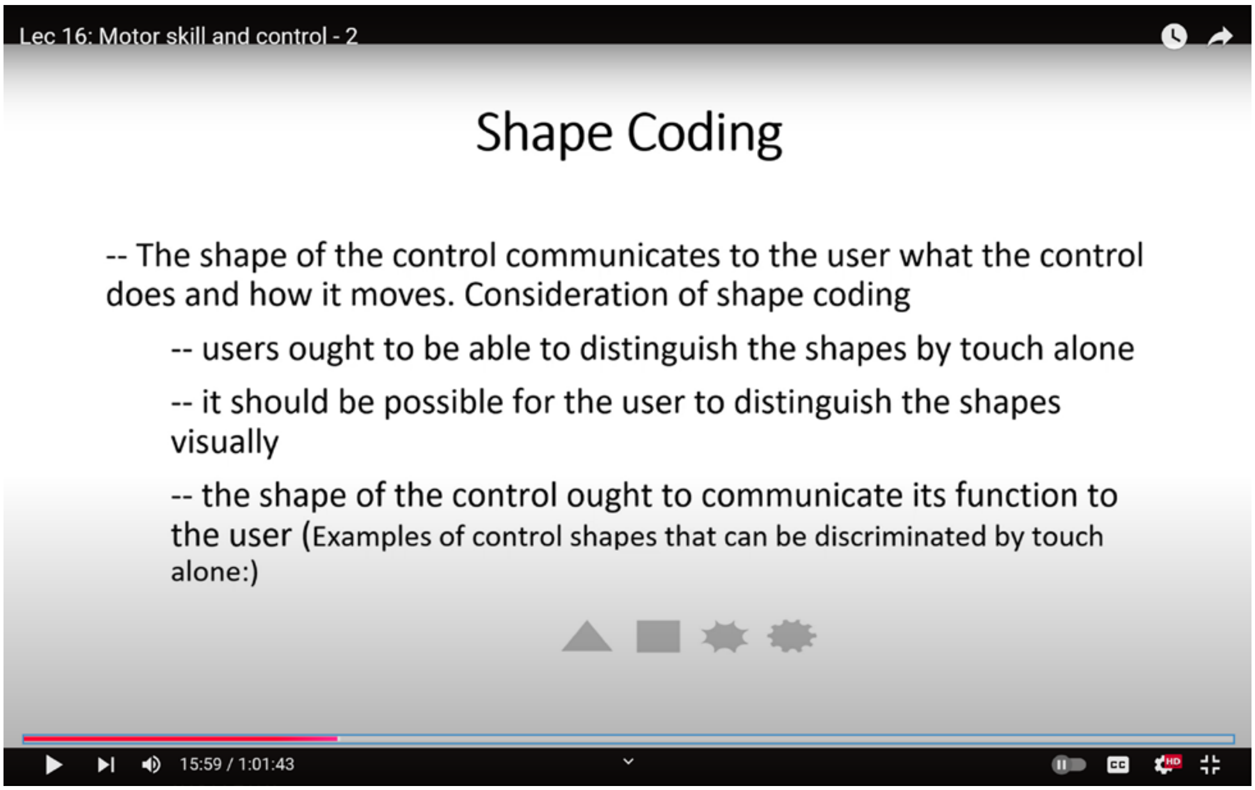

In a cockpit, various controls are designed with different shapes. For example, the control for the wing flaps on an aircraft is shaped like a flap, and its purpose is to increase air resistance, facilitating landing or takeoff. Similarly, the control used for lowering the landing gear is shaped like a wheel; moving the control down lowers the wheel, while moving it up raises it. This type of shape coding simplifies the execution of numerous control operations.

The shape of a control communicates to the user its function and the manner in which it operates. By utilizing distinct shapes for different controls, users can more readily understand how these shapes correspond to the functions of the machine, as well as which part of the machine is associated with each control.

The structure and function of the machine component controlled by a lever can be effectively coded using shape control. Users should be able to distinguish the shapes solely by touch. One aspect that facilitates shape coding is the notion that users can interact with a control while their eyes are occupied with other tasks. The tactile experience alone can provide insight into the intended function of the control. For instance, the rectangular shape of the flap control differs from the circular shape of the wheel control.

Moreover, when designing shape controls, it is essential that users can visually differentiate the shapes as well. This means that users should be able to recognize the shapes of various controls visually, allowing them to discriminate among them. Additionally, by observing the controls, users should be able to infer the functions of each control. The shape of a control communicates its intended function to the user.

Examples of shape controls that can be identified by touch alone include shapes such as triangles, rectangles (or squares), hexagons, and octagons. Users may find preference for specific shapes, which are commonly found in gears and levers, as well as shapes resembling steering wheels. Thus, these four different shapes, along with others like squares or straight-edged shapes, can be employed to create controls that are effectively mapped to their corresponding functions.

The second type of control factor we will discuss is label coding. Labels can also be utilized to designate certain types of controls or levers. Sometimes, the intended use of controls is evident. For instance, door handles are designed to be pulled, while push plates on doors are meant for pushing. However, one significant issue with many doors is that they are not properly coded. Donald Norman has conducted extensive work on poorly designed doors, coining the term "Norman doors" to describe them. Observing your surroundings, you might notice that door handles can provide misleading information, creating confusion for users. For example, a door handle implies that it should be grasped and pulled towards oneself, suggesting that the door opens outward. Conversely, a push plate indicates that pressure should be applied to move the door away.

However, many doors with push plates do not allow for motion in that direction. In some cases, a push plate may be used as a handle, leading to the confusion of pulling the door towards oneself. These issues can be categorized as label control-related problems. Fortunately, these controls can be improved through the use of appropriate labels.

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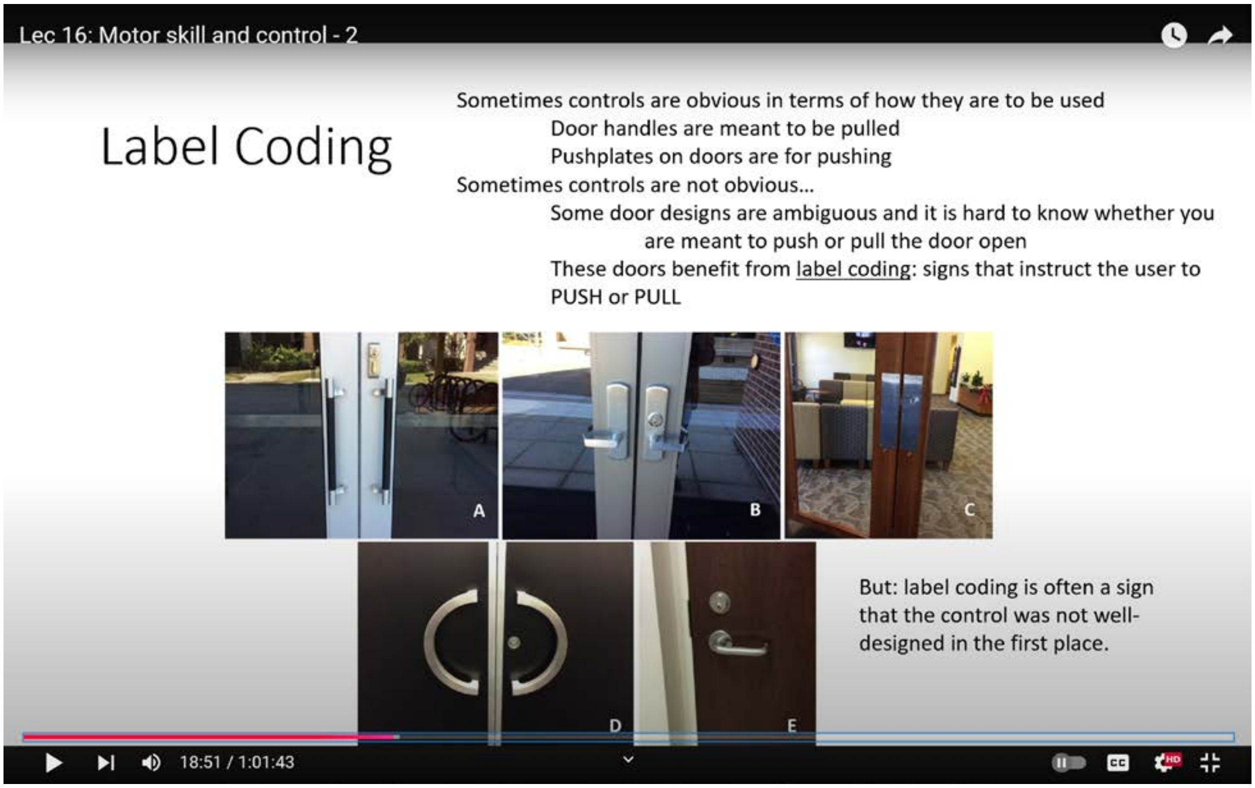

In situations where controls are not intuitively clear, some door designs can be ambiguous, making it difficult to determine whether one should push or pull. For instance, doors equipped with motion sensors or automatic glass doors can present challenges when the sensor malfunctions. In such instances, users may be left uncertain about how to open the door. Providing clear labels indicating the required action can be helpful.

For comparison, consider the doors on a metro train. These doors feature labels that change color, typically turning green or red. A green signal indicates that pressure can be applied to open the door, while a red signal advises against it, suggesting that applying pressure will not result in the door opening. Thus, even doors that do not operate through conventional means can benefit from effective labeling to enhance user understanding.

However, some door designs remain ambiguous, making it hard to ascertain whether one should push or pull. These doors could greatly benefit from label coding, using signs to instruct users on the required action. It is common to see doors labeled with instructions such as "push" or "pull," which clarifies the necessary movement. Given that each door is mounted on hinges that allow only specific movements, label coding enhances the ease of door operation.

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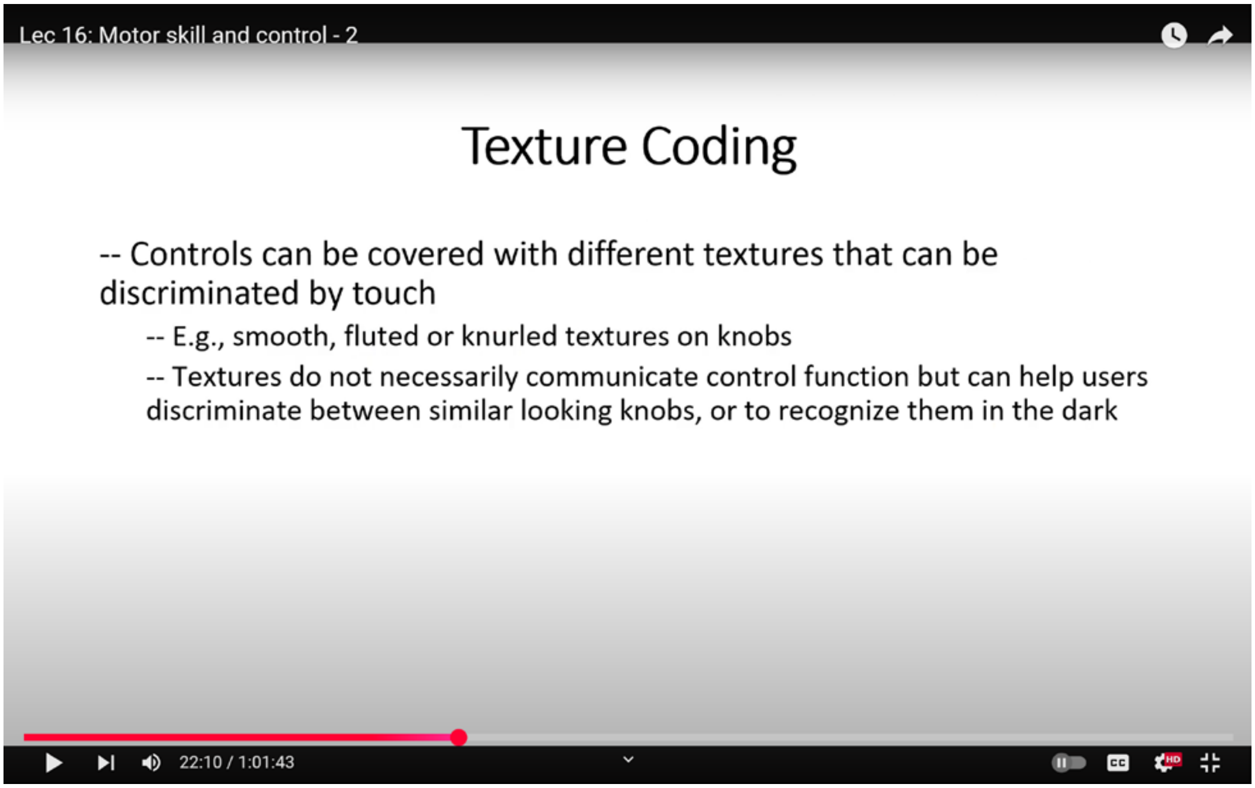

Another factor that can contribute to coding a control is texture. Controls can be covered with various textures that can be identified through touch. Some controls are designed to be smooth, suggesting a smooth motion, as seen in knobs on radios or other equipment. In contrast, certain controls feature grooves on the dial, indicating that the movement should be discrete rather than continuous, suggesting that smooth motion is not feasible.

Examples of texture coding include smooth, fluted, or knurled textures on knobs. While textures do not inherently communicate control functions, they can assist users in distinguishing between similar-looking knobs or recognizing them in low-light conditions. Therefore, two benefits of utilizing texture are the ability to differentiate one knob from another based on texture and to facilitate recognition in dimly lit environments.

If a knob features a smooth versus a fluted exterior texture, users can identify which control they are using by touch alone, even in darkness. This presents an interesting approach to coding controls. Colors can also serve as a coding mechanism for controls; however, distinguishing controls by color necessitates careful consideration of the user's visual abilities. This includes the capacity to differentiate shades of color, particularly under varying lighting conditions and levels of visibility.

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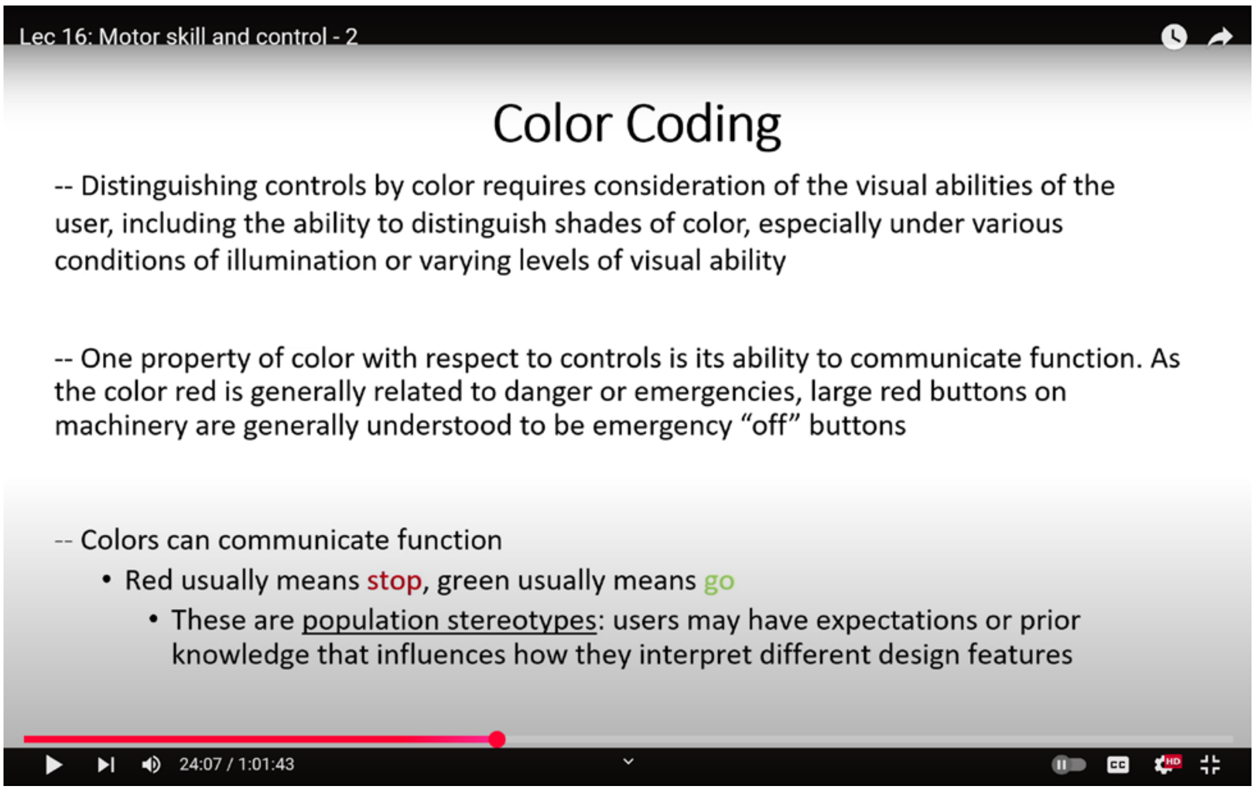

When designing controls that incorporate color, designers must keep in mind that individuals perceive colors differently due to genetic factors or other physiological conditions. Consequently, while utilizing color in control design, it is crucial to account for aspects related to the ability to discern colors, as well as the fact that certain colors may only be visible under specific lighting conditions. In some instances of extreme darkness or brightness, these colors may lose their essential property of being identifiable.

Designers should also consider the implications of color in relation to communicating functions. For example, the color green typically indicates "go," while red signifies "stop." Such color differentiation allows users to quickly understand the function of a control. Additionally, red is often associated with emergency stops, whereas yellow usually indicates a need for caution. Thus, color can effectively describe the function of a control; large red buttons on machinery are generally recognized as emergency shut-off buttons.

Furthermore, there are population stereotypes associated with colors that can inform their usage in control design. Users may have expectations or prior experiences that shape how they interpret different design features. The term "population stereotype" refers to the fixed associations people have with certain coding systems; altering these established codes can lead to confusion. For instance, if a control were designed to switch the meanings of red and green to indicate "go" and "no-go," respectively, users could become perplexed, as they are accustomed to the traditional green for "go" and red for "stop." Thus, when designing controls that employ color coding, it is essential to consider these pre-learned behaviors regarding the functions of specific controls.

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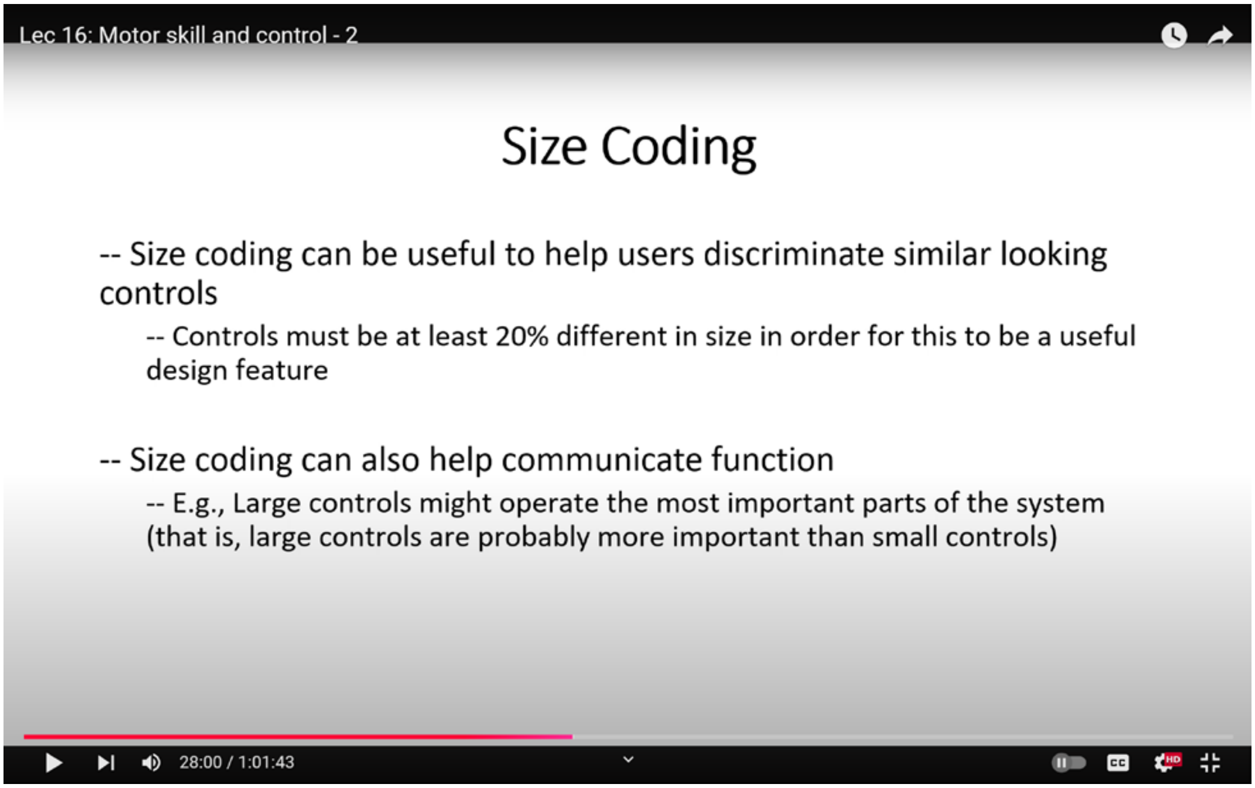

Size can also serve as a coding method for controls. While size is not always a significant variable in coding, it can help users distinguish similar smaller controls. To be effective, however, size differences must be at least 20 percent. For example, in the case of two levers, the difference between their sizes should be substantial enough to facilitate recognition.

Consider the example of a tractor, which typically has two levers: one for gear selection and another for controlling forward or backward motion, as well as the speed. The lever for quick and slow motion is smaller, nearly 50 percent the size of the larger lever that controls speed settings such as 1, 2, and 3. This illustrates the effective application of size coding.

Furthermore, size can communicate functional importance; larger controls may operate more critical system components, indicating their significance compared to smaller controls. In the tractor example, the quick and slow speed control is less critical for farming tasks and is primarily needed when traveling on roads. In contrast, the gear selection lever is crucial as it directly affects the tractor's speed and operation, similar to equipment like a Fromm thresher attached to the tractor.

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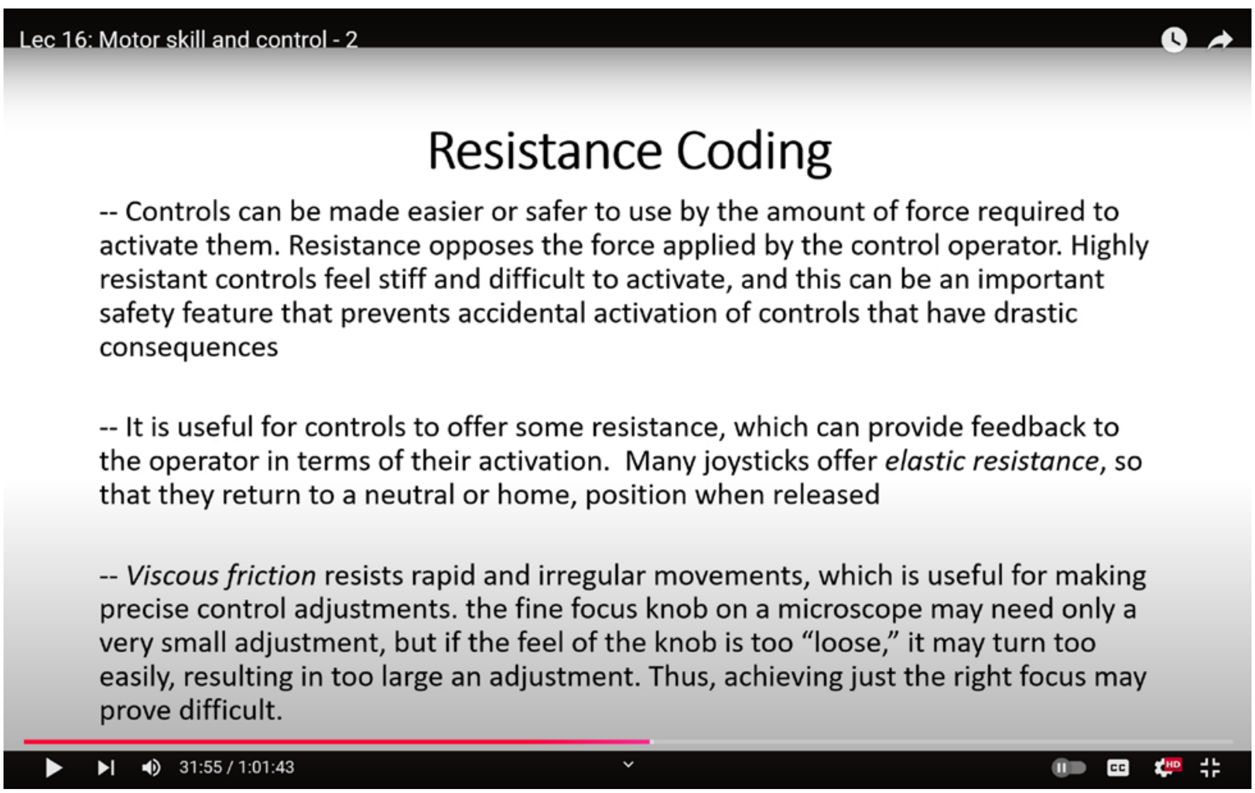

Another intriguing coding mechanism is resistance. Certain controls are designed to provide resistance, signaling to the user that they are intended for important functions. For instance, stop signs or stop buttons on equipment typically exhibit considerable resistance, indicating that their operation will lead to significant actions. Similarly, chains used for pulling trains offer resistance, reminding users that engaging these controls initiates unusual functions that may differ from standard control operations. For example, the lever on a microscope may also exhibit resistance, reinforcing its specialized function.

The rotary control cannot be operated with quick actions; instead, it functions through discrete movements that require resistance. This design ensures that small or simple movements of the microscope dial lead to larger changes in focus. Consequently, these controls are intentionally designed to resist very small and rapid movements.

Controls can be made easier or safer to use by adjusting the amount of force required to activate them. Resistance opposes the force applied by the control operator. Highly resistant controls feel stiff and are difficult to activate, which can serve as an important safety feature that prevents accidental activation of controls with significant consequences. This resistance communicates to the user that engaging with this control will initiate an unusual action. For instance, when a user presses an emergency button, they quickly realize that such an action is not necessary during normal situations, leading them to reserve that action for emergencies.

It is advantageous for controls to provide some level of resistance, as this can offer feedback to the operator regarding their activation. Many joysticks, for example, incorporate elastic resistance, allowing them to return to a neutral or home position when released. If you have played games on a gaming console, you will recognize that the joystick provides a certain kind of elastic resistance in response to your movements. This feature serves as a warning or information regarding the system's state. Friction in these controls helps resist rapid and irregular movements, which is essential for making precise adjustments.

In the case of a microscope, the fine focus knob may require only a minimal adjustment. However, if the knob feels too loose, it could turn too easily, resulting in an excessive change in focus. Since smaller movements can lead to significant changes in focus in microscopes, the knobs are designed with greater resistance, ensuring that only a minimal amount of pressure is applied, thus facilitating the desired adjustments. Viscous friction is another method of resistance coding in controls.

Another approach to coding controls involves their location. The placement of controls can indicate their functions, help differentiate similar-looking controls, or serve for convenience. For instance, light switches are often positioned near doorways, as are emergency shut-off controls. The location of a control plays a crucial role in helping users discriminate between different controls and understand their functions. An example of this is light switches positioned by doorways or emergency controls situated near exits. When inside a room, there is no need for an emergency shut-off control to be placed away from the door; if an emergency arises, such a control should be easily accessible to facilitate a quick exit.

While the placement of a control may sometimes seem arbitrary, it is often based on user expectations that cannot easily be rearranged. These user expectations are known as population stereotypes, which arise from shared beliefs or expectations within a given user population. Occasionally, the location of controls may not align with these expectations, yet designers may choose not to alter them due to the familiarity users have developed over time.

For example, in a car, the accelerator, brake, and clutch are controlled by different feet: the right leg operates the accelerator and brake, while the left leg controls the clutch. In contrast, driverless cars and automatic vehicles typically feature only two controls, one for the brake and one for the accelerator. In these cases, the brake, an emergency function, is still assigned to the right leg, while the accelerator is operated by the left leg. Good control design would suggest that the dominant leg should control the brake and the non-dominant leg the accelerator. However, users have become accustomed to the established control configuration, making any changes challenging.

This prior learning, which fosters user comfort with potentially suboptimal control designs, is referred to as population stereotypes. These stereotypes also apply to location coding, such as sinks or tubs with separate knobs for controlling hot and cold water. It is common for the hot water control to be positioned on the left, while the cold water control is on the right. This convention holds true in hotels and various locations around the world. If, for design purposes, these controls are switched or a single knob is introduced to control both hot and cold water, users will still instinctively turn the knob to the left for hot water and to the right for cold water. Any alteration to this learned behavior would pose challenges for users.

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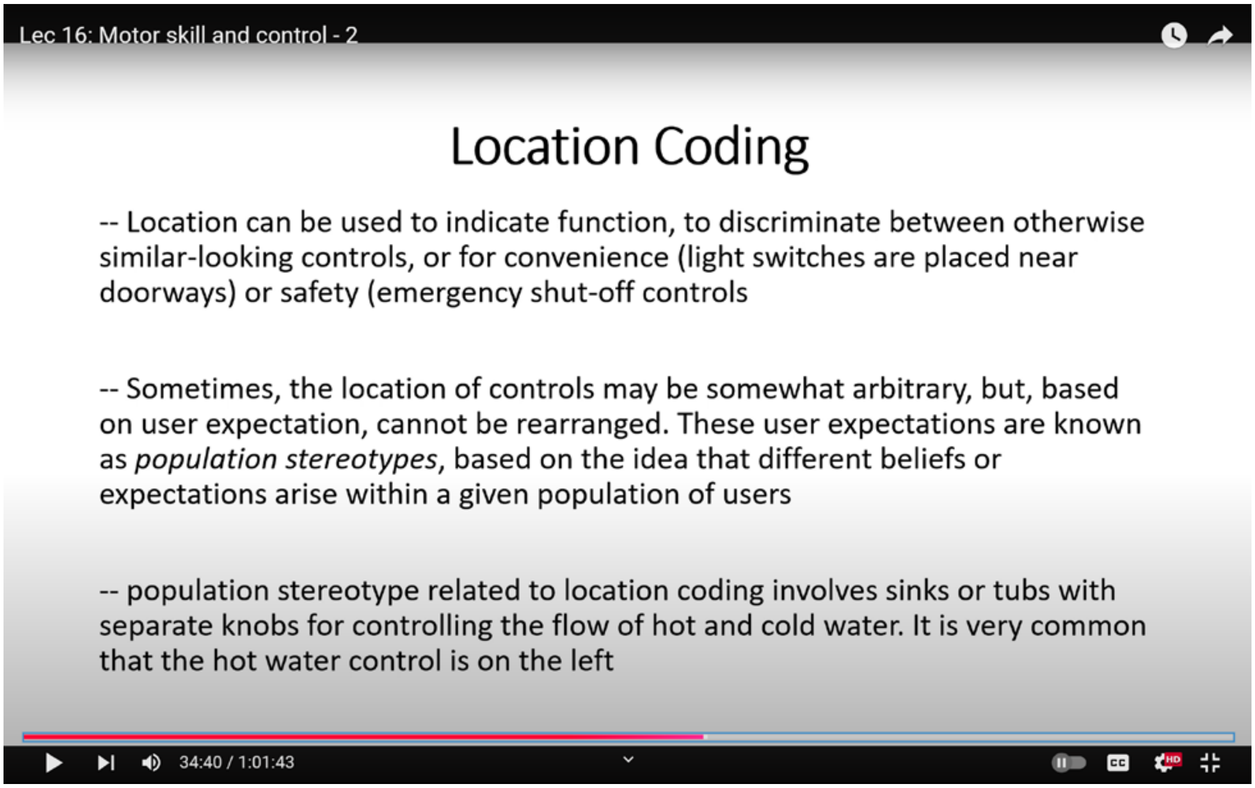

Maintaining the association of function with the movement of the control is known as a population stereotype. The location of a control relative to the system it governs can significantly aid in communicating its function. By placing the control next to the object it controls, designers can enhance user understanding and accessibility.

If you examine the two different arrangements of gas stoves with distinct controls, you will notice that arrangement A is superior due to its effective use of size coding and location coding. Conversely, arrangement B, which lacks both size coding and location coding, is commonly found in gas stoves. Despite its deficiencies, users are accustomed to arrangement B and are satisfied with it, making them resistant to switching to arrangement A.

Similarly, computer controls, including keyboards and mice, are designed to foster user familiarity. The QWERTY keyboard layout, which is widely used, and the motion of the mouse for text input have become so entrenched that any proposed changes to the keyboard layout are often met with resistance, leading to significant user challenges. Although the QWERTY layout is not particularly favored from a cognitive perspective, it remains prevalent.

Two keyboard designs are often compared: the conventional QWERTY keyboard and a modified version known as the Dvorak Simplified Keyboard. Research indicates that the Dvorak keyboard significantly outperforms the QWERTY design in terms of data input efficiency. However, users are so accustomed to the QWERTY layout that they tend to stick with it. The QWERTY layout, in particular, is designed to slow down the typing rate. This raises the question: why do we not transition to a faster layout, such as the Dvorak keyboard? The simple reason is that people feel comfortable with the current keyboard configuration and are generally unwilling to change.

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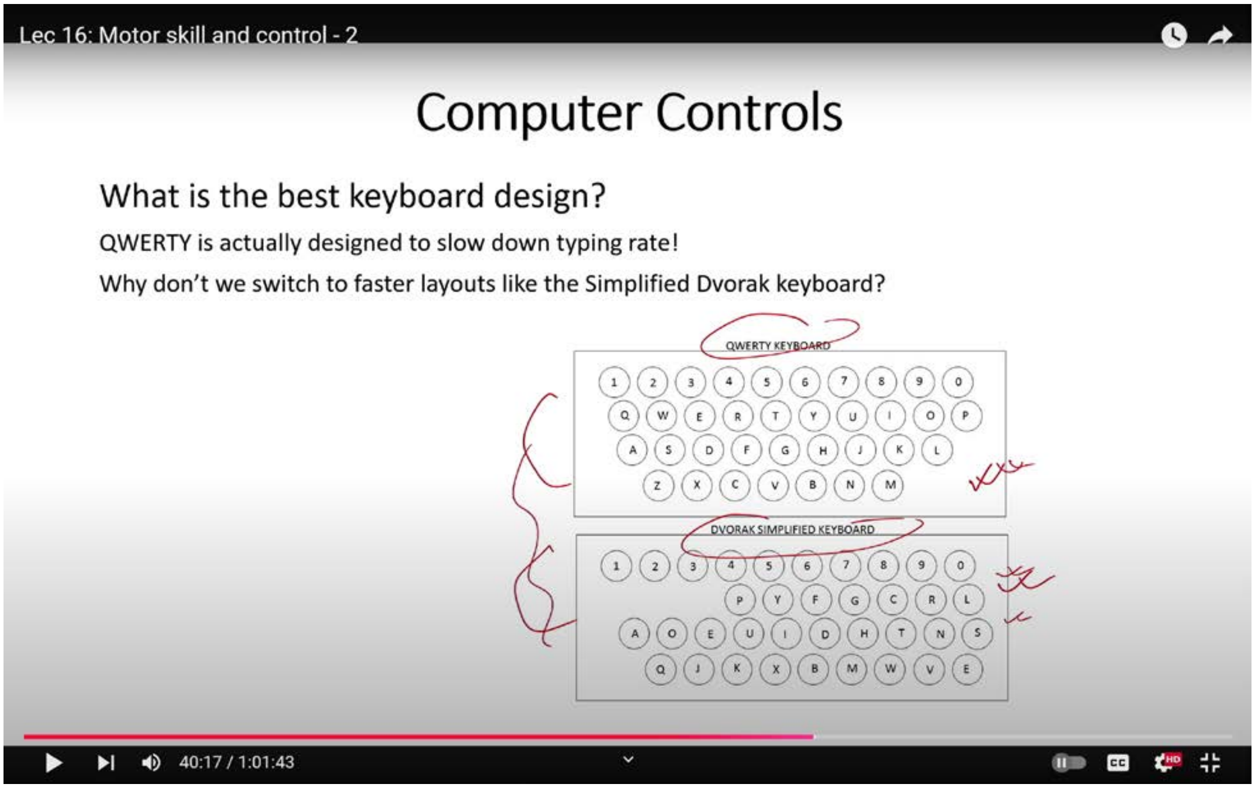

Another critical factor in control design is known as control-display compatibility. This concept refers to the relationship between the control movement and the corresponding display movement, as well as how the display signals the control action. Control-display compatibility can be understood in two primary contexts: spatial compatibility and movement compatibility.

Spatial compatibility refers to how the arrangement of controls should correspond with the spatial arrangement of the display or the system being controlled. For instance, in the gas stove example previously discussed, good spatial display compatibility means that each control should be linked directly to its respective burner. In contrast, if the controls are not spatially arranged to reflect the corresponding burners, users may struggle to determine which control operates which burner. This lack of clarity makes it challenging for users to understand whether to adjust a specific control.

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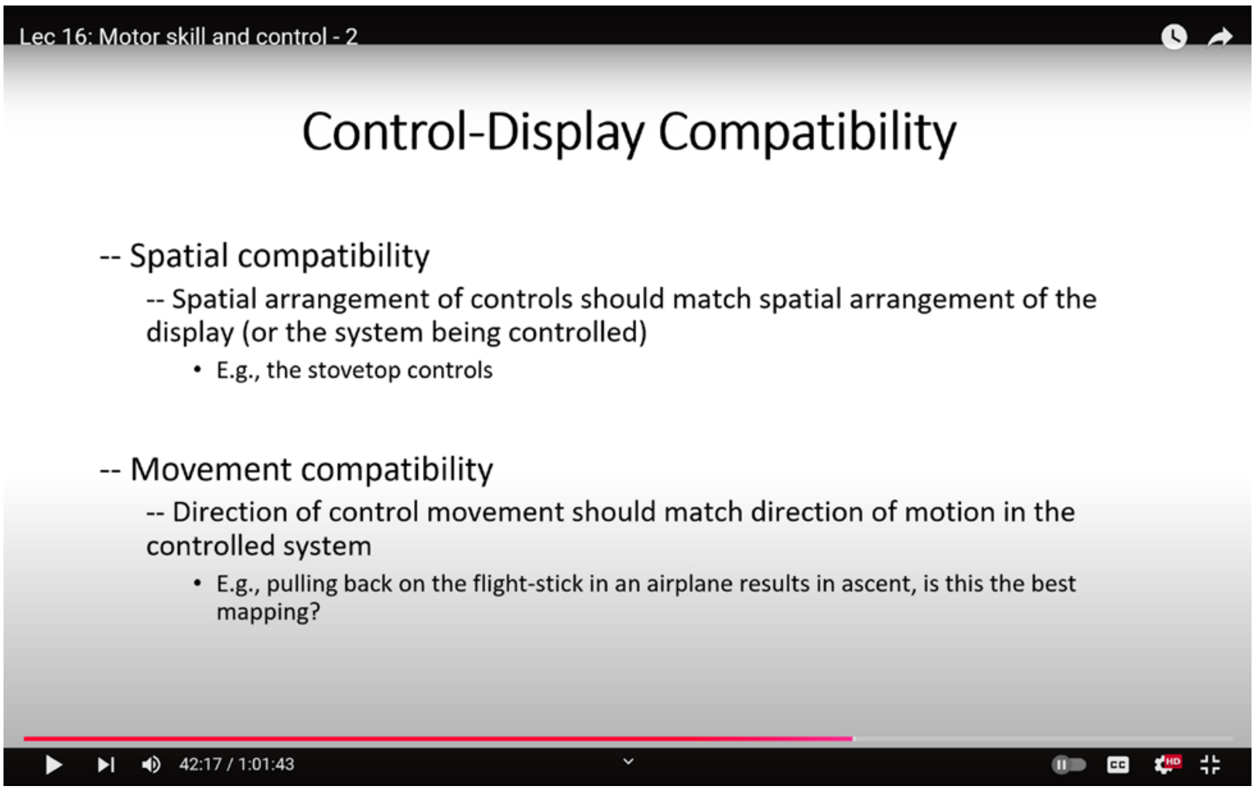

Designers must also be aware of movement compatibility, which dictates that the direction of control movement should correspond to the direction of motion in the controlled system. For example, pulling back on an airplane's flight stick typically results in an ascent. Movement compatibility suggests that the motion of the control lever should directly relate to the action of the vehicle. For instance, pressing the gas pedal in a car causes the vehicle to move forward, which can be counterintuitive, as pressing generally implies applying force downward, yet the car moves forward instead of downward.

A relevant example involves a flight control system where pulling the lever back raises the aircraft, while pushing it forward causes a descent. This setup can create confusion because the control movement does not match the expected motion of the aircraft. A more intuitive design would have a vertical control, where moving the control up raises the aircraft and moving it down lowers it. This alignment would create a more compatible and understandable user experience.

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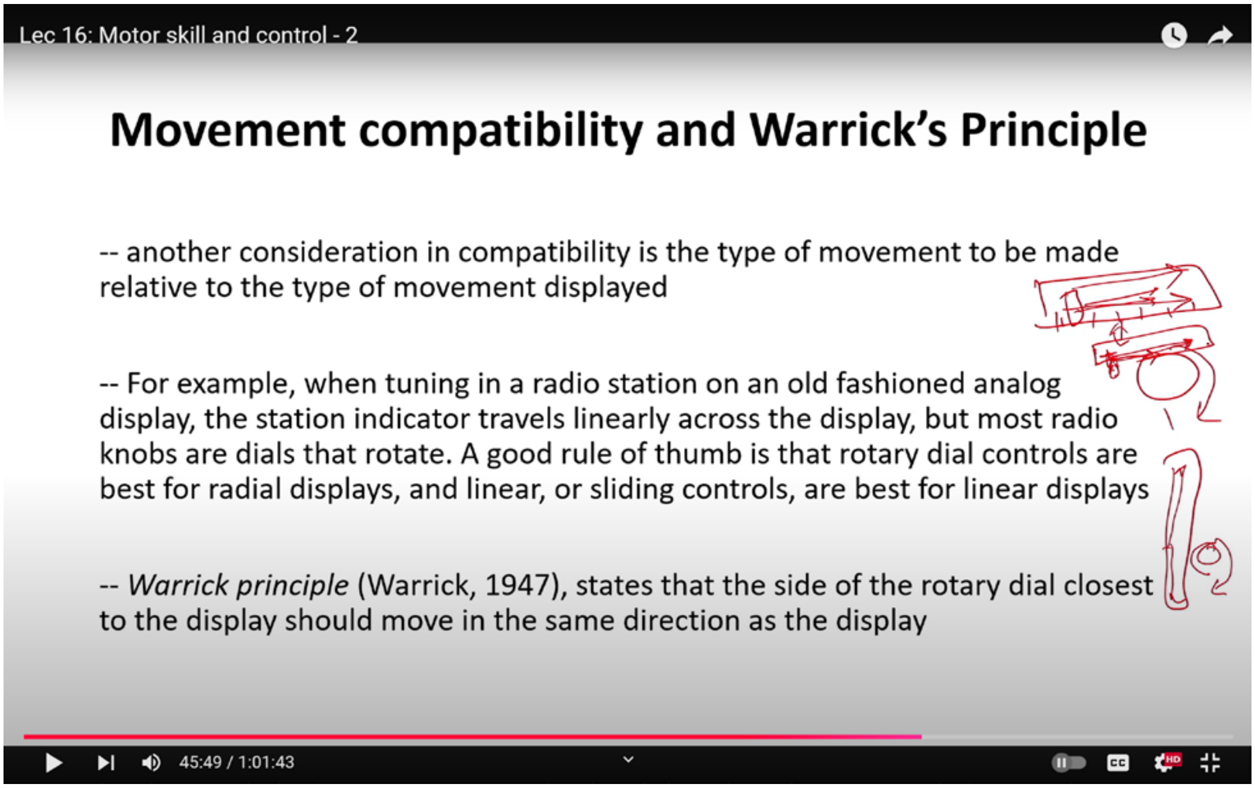

Another aspect of movement compatibility relates to the type of movement to be made and how it corresponds to the movement displayed. Consider older radios that featured knobs for tuning. When you turned the knob in a circular motion, the station changed linearly. This is an example of incompatible movement, as the knob's circular motion does not align with the linear movement of the station indicator. An improved design would involve displays that reflect this interaction, such that turning the knob in one direction would cause the display to move in the corresponding direction, creating a more coherent and user-friendly interface.

This method of displaying motion is far more effective than a linear approach. For example, when tuning a radio station using an old-fashioned analog display, the station indicator moves linearly across the screen. However, most radio knobs are designed as rotating dials. A useful guideline is that rotary dial controls are most effective for radial displays, whereas linear or sliding controls are more suitable for linear displays. Instead of utilizing a rotary control, a linear button could be implemented, where the motion applied to this button would correspond to the movement of the station or band selector, thereby establishing a more compatible relationship between the display and the control function.

Warwick's principle states that the side of the rotary dial closest to the display should move in the same direction as the display indicator. Therefore, if the display features a lever that moves linearly in conjunction with the station indicator, the motion of the lever should align with the movement of the indicator. Essentially, the edge of the knob that is nearest to the display must move in the same direction as the indicator. If the edge of the dial moves one way, the dial itself should also move correspondingly. This straightforward principle ensures that the edge of the indicator or pointer aligns its motion with that of the control display.

Additionally, there should be a control-display compatibility ratio that relates the size of the control movement to the size of the display movement. When using a rotary knob to manipulate the indicator on a linear display, one must consider how far the indicator should move in response to a quarter turn of the knob. This relationship must be balanced. For instance, when using a computer mouse, if you have a 16- or 19-inch screen, a small movement of the mouse results in a significantly larger movement of the on-screen pointer.

The relationship between mouse movements and display movements is often non-linear. The control system is influenced by speed and motion dynamics. Smaller ratios are beneficial for precise positioning, such as tuning a radio station, where large rotations of the knob should produce only small movements of the indicator. Conversely, larger ratios are advantageous for covering greater distances; for example, when moving a mouse pointer across a large monitor, small mouse movements should correspond to significant movements on the screen. This illustrates how compatibility should be established, not as a one-to-one relationship, but in a way that smaller physical movements of the mouse lead to larger corresponding movements on the display.

Tracking occurs when we manipulate a control and observe how the system responds, characterized by continuous operations and observations of the system state, forming what is known as a tracking loop, akin to a feedback loop. Consider the act of driving a car; tracking is evident as we adjust the speed or steer left and right. The small movements of the steering wheel allow us to keep the vehicle aligned within the lane. Thus, we continually track the relationship between our steering movements and the vehicle's actions.

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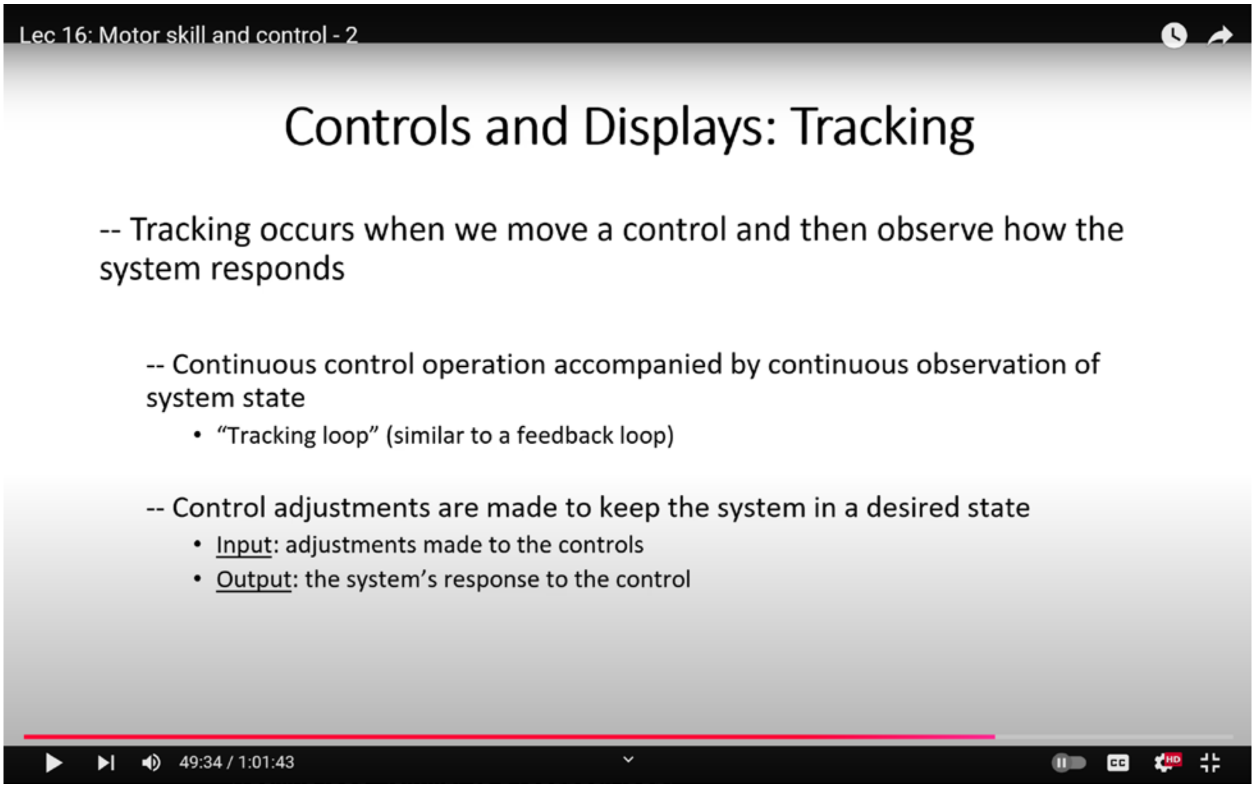

The steering wheel exemplifies a negative feedback loop because it provides feedback about the effects of our actions. It does not explicitly show us whether our inputs lead to the desired outcome, but it indicates if corrections are necessary to maintain the correct trajectory. This negative feedback is crucial for determining whether the vehicle is oriented correctly based on adjustments made to the steering wheel.

Another critical aspect to consider is the dynamics of tracking and control. Control dynamics defines the relationship between command input and the system's response. The order of control signifies the complexity of this relationship. Control dynamics encompasses the relationship between tracking an object, such as a vehicle, and the control inputs applied to it. Various types of control dynamics correspond to different kinds of tracking controls.

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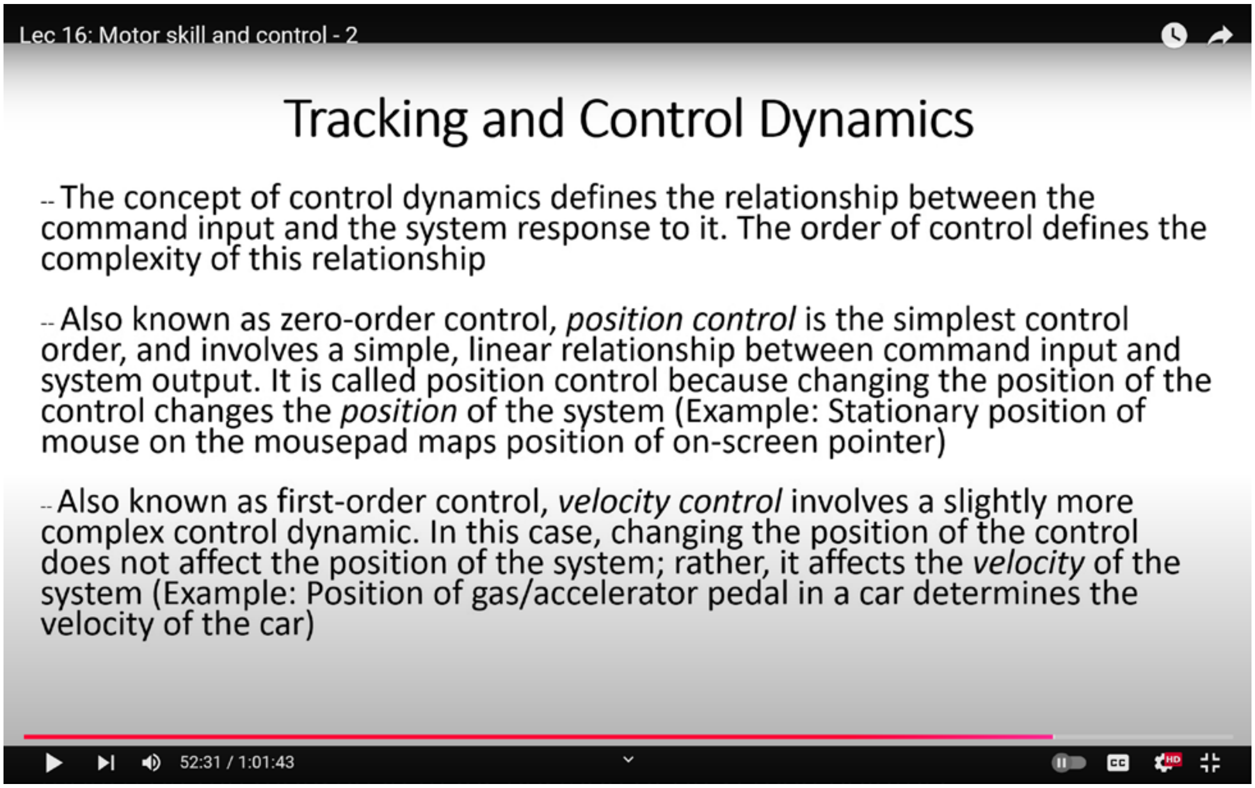

Zero-order control, also known as position control, is the simplest type of control and signifies a straightforward linear relationship between command input and system output. This control type is called position control because altering the control's position directly influences the system's position. An example of this is the stationary position of a mouse on a mouse pad mapping to the on-screen pointer's position. Here, tracking occurs based on the movements executed and the functions performed by the control.

This mapping between the two elements represents an understanding of tracking and control dynamics. In zero-order control, the relationship is one-to-one. For instance, the position of the mouse on the mouse pad directly corresponds to the movement of the pointer on the computer screen, demonstrating a first-order relationship between the physical action on the mouse and the resulting action on the screen pointer.

First-order controls are not directly correlated with the motion of the operator; instead, the operator's motion is translated into a first-degree control. This concept, also known as first-order control, involves velocity control, which entails more complex control dynamics. In this case, the relationship between the control and the operator's motion is not a direct one-to-one correspondence; rather, it is mediated through a different framework or function. When the position of the control changes, it does not directly affect the system's position; instead, it influences the system's velocity. For example, adjusting the position of the gas accelerator pedal in a car determines the vehicle's velocity. Pressing the pedal translates into the car's speed, but it does not translate into how much the car physically descends. Thus, pressing the pedal influences the car's motion without directly controlling it, as this motion is converted into speed, which constitutes a second-order function.

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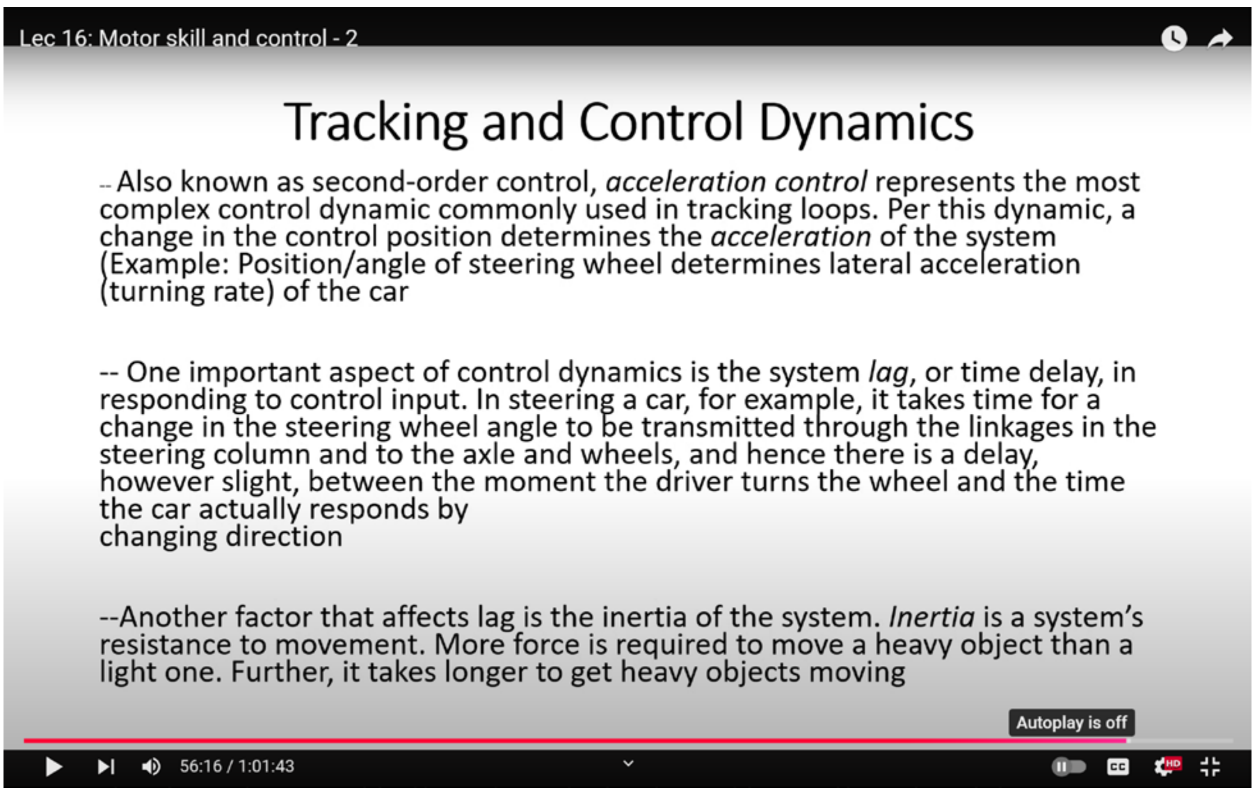

There is also a third-order function known as acceleration control, which represents the most complex control dynamics commonly encountered in tracking loops. In this context, a change in the control position determines the system's acceleration. For example, the position or angle of the steering wheel influences the car's lateral acceleration or turning. Simply moving the steering wheel does not indicate the angle at which the car is moving or turning. Instead, this is defined by the wheel's motion and the car's speed. The interplay between the wheel's speed and the motion manipulated through the steering wheel ultimately determines the angle at which the car will turn. Thus, this constitutes a third-order control. The movement of the steering wheel does not directly correspond to the same degree of motion of the vehicle's wheels. For instance, if the steering wheel is rotated multiple times, this does not translate to the car's wheels turning an equivalent number of times; a full rotation of the steering wheel will not cause the car to complete a 360-degree turn. Rather, the total rotation of the steering wheel translates into the motion of the wheels, in conjunction with the car's speed, which collectively determines the angle and extent of the car's turn, constituting a second-order control.

An important aspect of control dynamics is system lag, or the time delay in responding to control inputs. For example, when steering a car, there is a time lag between the angle at which the steering wheel is turned and the corresponding changes transmitted to the linkages in the steering column and the axle of the wheels. Consequently, there is a slight delay between the driver's actions in turning the wheel and the car's response in changing direction. This lag must be recognized, as the motions applied to the control are not directly converted into immediate control actions.

Another factor contributing to lag is the inertia of the system. Inertia refers to the system's resistance to movement; more force is required to move heavier objects compared to lighter ones. Additionally, it takes longer to accelerate heavy objects. For example, consider a large truck. The pressure applied to the pedal does not directly correlate with the truck's speed. When too much pressure is applied slowly, the truck will gradually accelerate, but the speed will vary based on whether the truck is loaded or unloaded. When loaded, the truck takes longer to reach a certain speed, and stopping it becomes more challenging, resulting in inertia-related lag. In contrast, when the truck is empty, its speed is more directly related to the pressure applied to the pedal.

Tracking and display system states are crucial in this context. A key component of tracking tasks is the nature of the display, which provides the operator with information about the system's state and the effects of their commands. Drivers rely on speedometers to give feedback about the car's response to acceleration, as well as visual cues from the front end of the car and the lines of the road seen through the windshield to assess the vehicle's response to steering. Typically, drivers monitor their steering wheel, the side of the road, and the speedometer to evaluate whether they are driving within the correct lane or if their driving is adversely affected.

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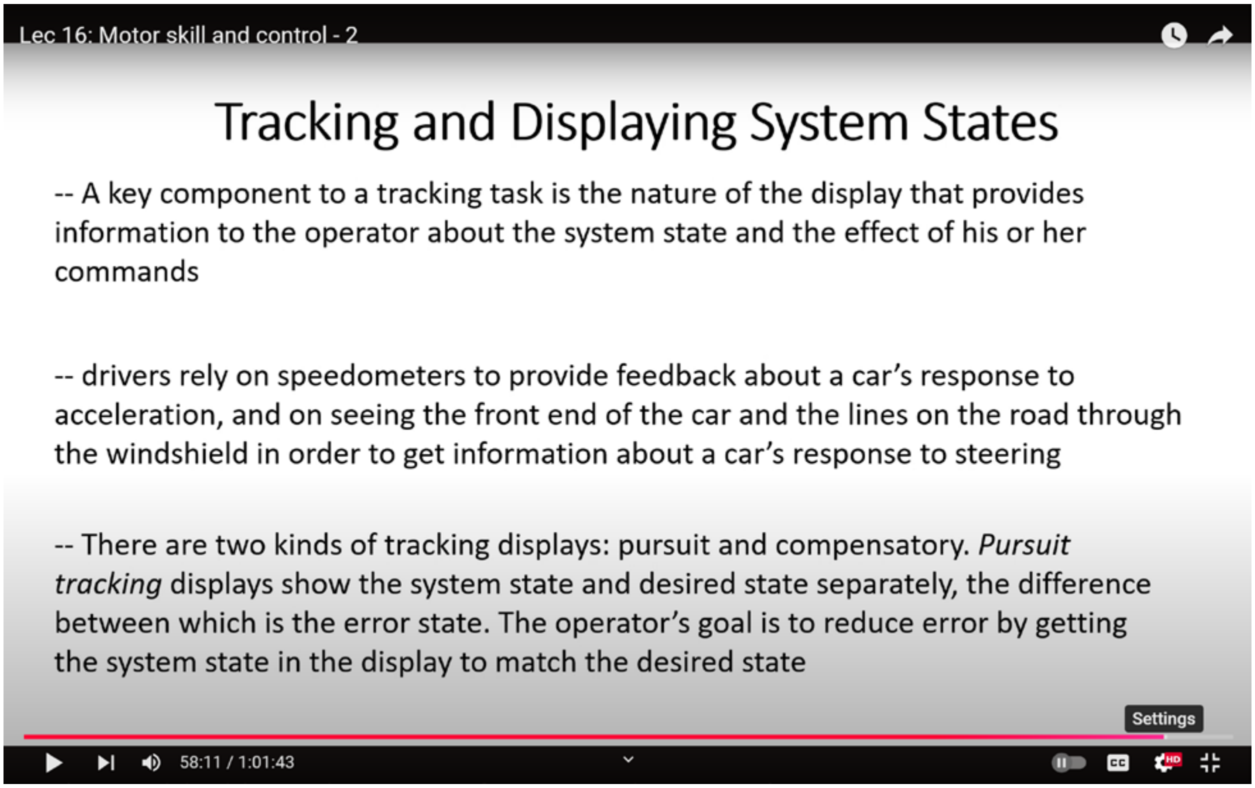

There are two types of tracking displays: pursuit displays and compensatory displays. A pursuit display shows fixed positions, representing both the starting and final positions. This type of display tracks the system state and the desired state, with the goal of reducing the error by aligning the system state on the display with the desired state. For example, by observing the curb on both sides of the road and the vehicle's front end, a driver can position the car appropriately within the lane, ensuring safety. This is classified as a pursuit display. In contrast, compensatory display tracking presents only the error state, indicating the discrepancy between the actual and desired states without providing the broader context of the system state.

The compensatory display will indicate how much error you are committing, but it will not provide information about the desired state or what actions you should take. It does not inform the operator whether the error state arises from a deviation in the system, meaning the car has moved away from the desired state, or from a deviation in the control state, where the steering wheel has moved away from its desired position. Nevertheless, the operator can use this information about the existence of errors to take corrective action.

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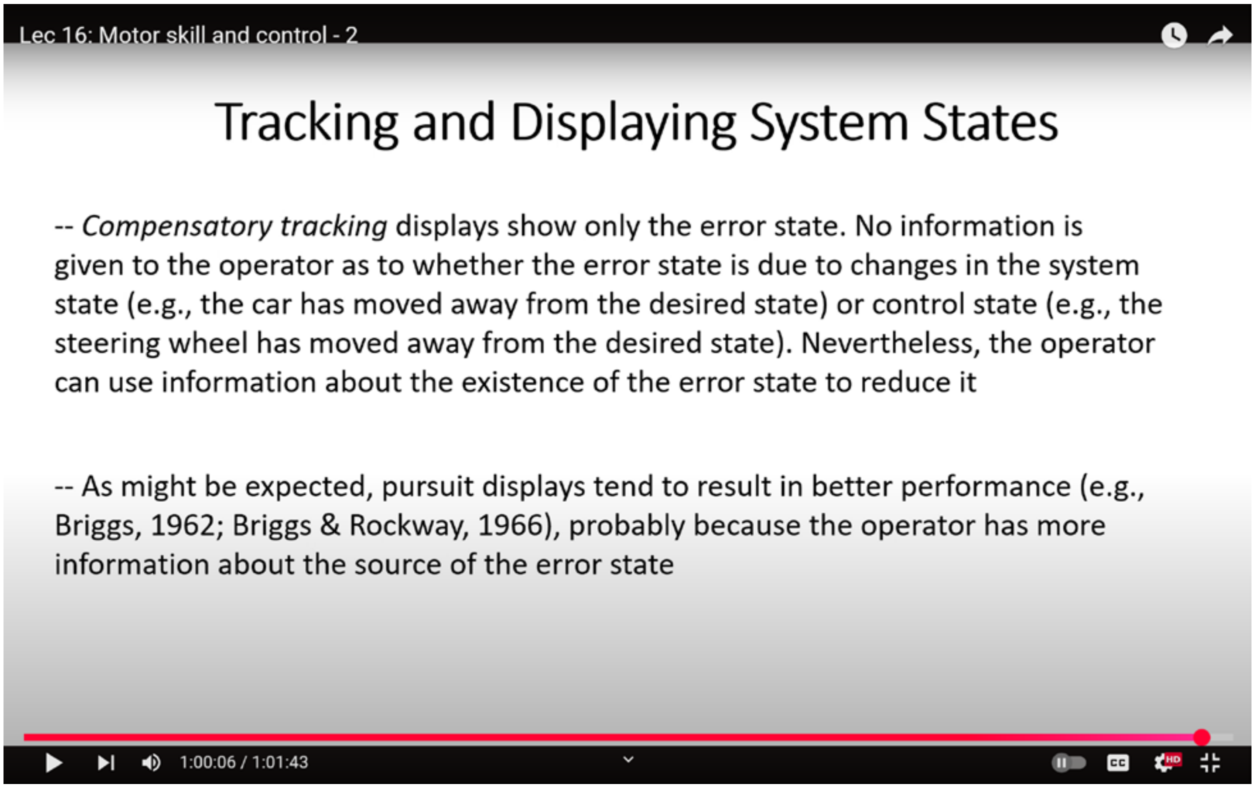

For instance, while driving, if another vehicle honks from behind, you become aware that you have crossed the lane marker and need to correct your position to return to your lane. In this error state, you find yourself between lanes and may be uncertain about how to realign your vehicle. To navigate back into your lane, you must monitor your speedometer, observe the steering wheel, and pay attention to the lane dividers. By combining all of this information, you can adjust your driving to position the car correctly within the lanes, allowing other drivers to resume their journey without honking at you.

This process is referred to as compensated tracking. Although you may not know the exact steps to correct the error, there are several actions you can take to rectify the situation. As expected, pursuit displays tend to yield better performance, likely because the operator has more information regarding the source of the error state. Pursuit displays are advantageous because they provide the operator with clarity about their current actions and where they need to be after making corrections. In contrast, compensatory displays lack this type of information.

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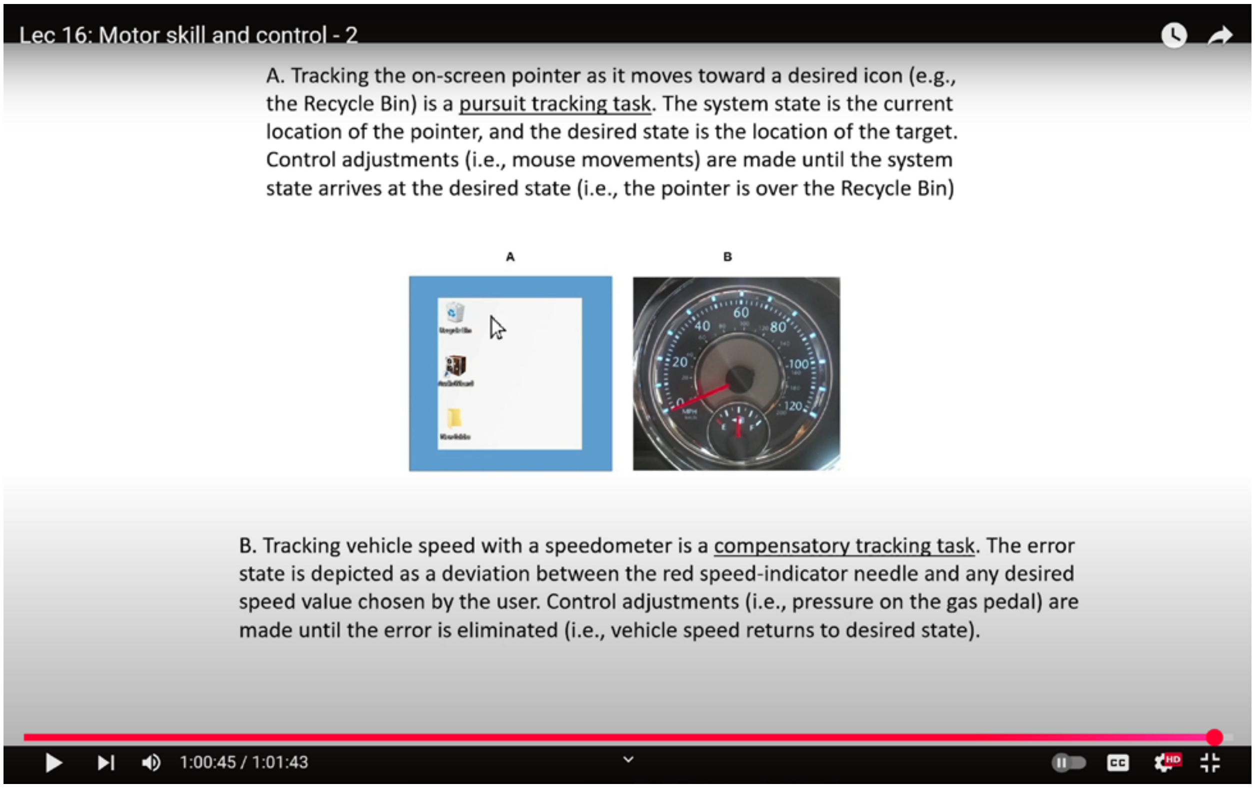

While compensatory displays provide extensive information on what actions should be taken and how to utilize this information to correct errors, they do not make it clear what the error is or where you should be. For example, on the screen, a tracking pointer moves toward the desired icon, representing pursuit tracking display, while the speedometer serves as a compensatory tracking display.

In today’s class, we explored controls, the design of controls, the various functions of controls, and the modifications that should be implemented in control systems to enhance operator interaction, leading to improved performance. This concludes today's lecture. Namaskar and goodbye from the MOOC studio.